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13. ABSTRACT

The transient aspects of the thermal defocusing of a CO_2 laser beam (10.6 μ) propagating through air doped with SF_6 have been studied using an infrared detector and interferometry. A comparison of these results with theory has shown that the defocusing occurring in air is qualitatively similar to that observed at 0.63 μ in liquid CCl_4 doped with iodine.

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THERMAL DEFOCUSING OF A CO_2 LASER BEAM IN AIR DOPED WITH SF_6

INTRODUCTION

This report presents a laboratory study of thermal defocusing in air using a CO_2 laser beam. Our philosophy in undertaking a small-scale experiment is to gain sufficient understanding of the phenomenon to predict the results of larger scale field experiments and to indicate the areas where the efforts with the larger and more expensive experiments should be concentrated. There are several advantages to performing a laboratory experiment rather than a field experiment if one wants to gain an understanding of the field situation. For example, beam quality, absorption coefficient, path length, wind velocity, and the homogeneity of the medium can be controlled. The medium itself can be varied as well as the beam diameter so as to change the time constants associated with conduction and convection effects. Since one can limit the number of interactions in the phenomenon, a theoretical description of the effects of each independent variable taken separately becomes feasible. Approximate theories for limiting cases may be more easily tested and generated. These separate analyses may then enable one to understand the more complex situation for which a purely mathematical analysis might be exceedingly difficult.

OBSERVATIONS

Intensity Profiles

The observations which we report here are of two different types which are designed to supplement each other. The first is the observation of the intensity profile of the defocusing beam as a function of time. The second is the observation, versus time, of the integrated index of refraction perpendicular to the defocusing beam. These observations clarify the processes of conduction and convection along the beam.

Figure 1 shows the experimental arrangement used to observe the intensity profile of the defocusing beam. The CO_2 laser beam had a power of 3.2 W and a power density at the center of 21 W/cm^2. It passed through a cell 16 cm in length which contained one atmosphere of air and enough SF_6 (less than 5 torr) to provide an absorption coefficient of 0.087 cm^{-1}. This is not enough to alter the bulk properties of the medium from those of air. The beam was then swept in a vertical plane past a gold-doped germanium detector by a four-sided rotating mirror moving at 1800 rpm.

The rotating mirror and the detector were also used to measure the Gaussian parameter of the laser beam as it entered the absorption cell. (The Gaussian parameter is defined here as the half width of the intensity profile at 1/e.) Figure 2 shows the measured laser intensity profile scaled to fit a Gaussian function. The good fit ensures that the laser was operating in the TEM_{00} mode. The Gaussian parameter β for the laser beam was found to be 0.22 cm.

Figure 3 shows the intensity profile of the defocusing beam at the indicated times measured from the moment of opening of an electromechanical shutter. A pulse from the shutter triggers the upper sweep of an oscilloscope, which is shown as the upper

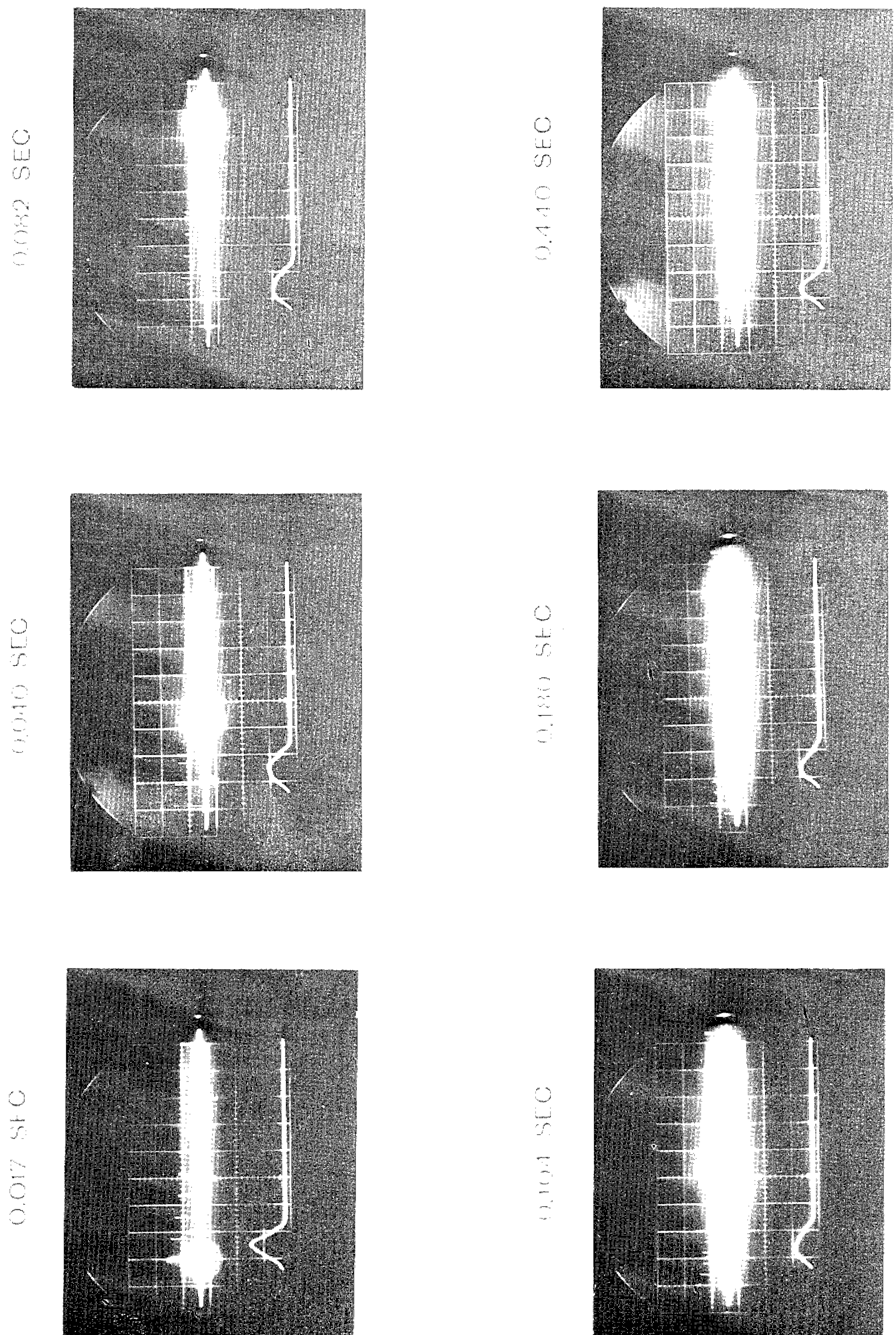

Fig. 3. - Intensity scans of defocusing laser beam. The times shown indicate the time that has elapsed since opening of the camera shutter.

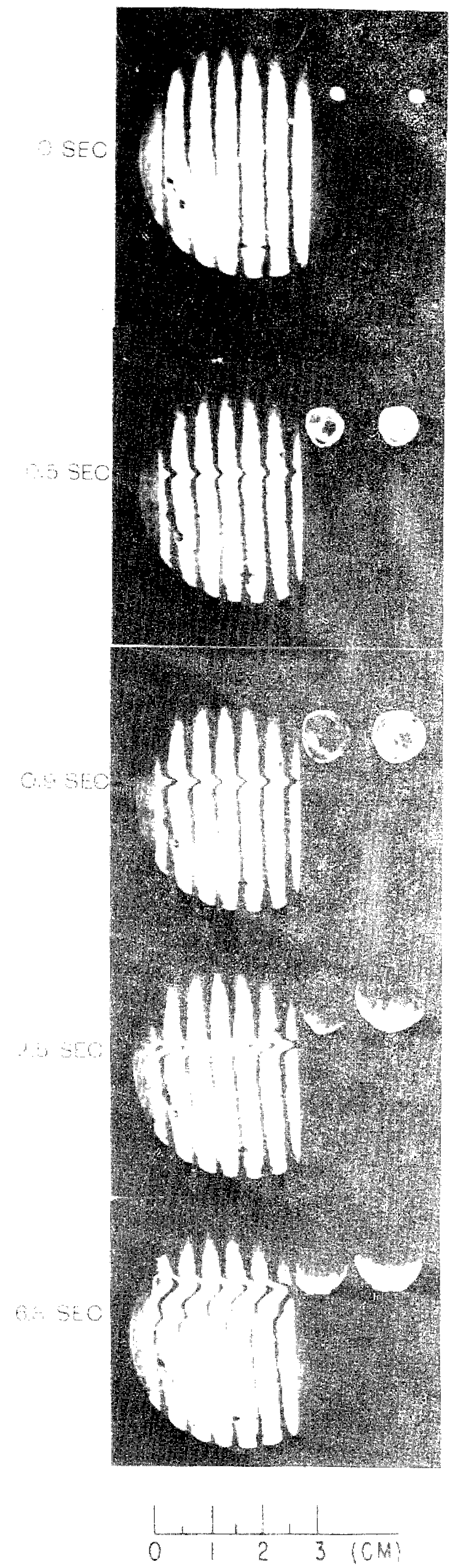

Fig. 5 - Interference fringe deflection due to the heating of CCl_4 by the absorption of He-Ne laser light (6328 Å). The heating beam passes through the cell horizontally from left to right. The time indicated on the left of each photograph is the time elapsed since turning on the laser beam. The two small patterns at the right show the thermally defocused laser beam as viewed 55 cm from the exit window of the liquid cell. (Two patterns are produced due to reflections from the two surfaces of the beam splitter.)

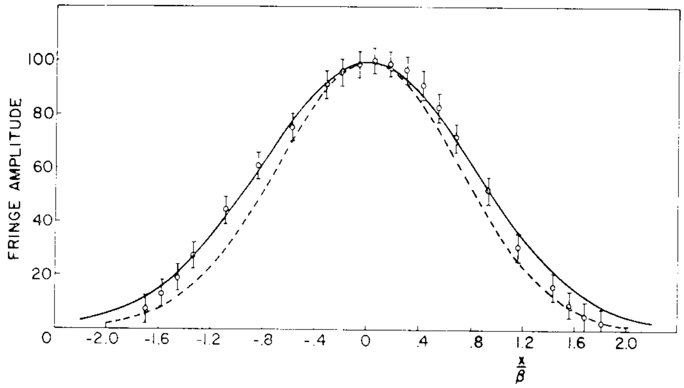

Fig. 7 - Fringe shape in air doped with SF_6 where $\tau_c = \beta^2/4K = 0.0576$ sec and t = 0.042 sec. Measured values are plotted together with their estimated error brackets. Solid line is a theoretical curve. The dashed line is the Gaussian heat source.

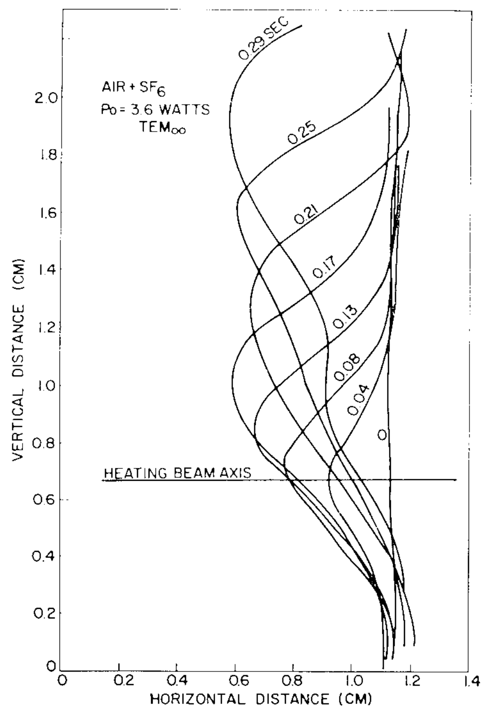

Fig. 8 - Composite fringe shapes at different times during thermal defocusing in air doped with SF_6.

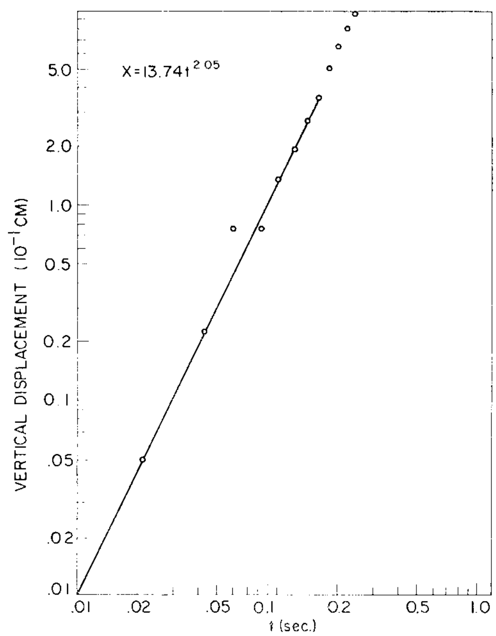

Fig. 10 - Log-log plot of vertical displacement of the fringe peak as a function of time.

$$t_2 = \left(\frac{I_1 \alpha_1 \beta_2}{I_2 \alpha_2 \beta_1}\right)^{1/3} t_1 .$$

Using the values obtained from the present experiment for the quantities with the subscript 1, and 0.05 secs for t_1 as the latest time for which convection could be neglected, a corresponding time can be computed for the case of propagation of wide laser beams in the atmosphere for the zero-velocity case.

If convection can be neglected, one may describe defocusing through the use of the aberrationless theory given by Akhmanov et al. (3). The Akhmanov equation can be optimally tested by observing thermal defocusing in ethylene glycol since the viscosity of this liquid is such that convection does not enter into the effect. Figure 11 shows a log-log plot of the Gaussian parameter divided by its zero-time value versus time, for a defocusing beam after transversing a cell of ethylene glycol and a small amount of dye. The curve was determined from a computer solution of the Akhmanov et al. equation shown at the right. The square root dependence on time of beam defocusing reported by Carman and Kelley (1) can be obtained from this equation. The experimental points were obtained by measuring the intensity versus time at the center of the defocusing beam. As may be seen, the experimental points fit the theoretical curve quite well. This result, together with the interferometric data presented above, indicates that the Akhmanov equation may be used to generate graphs of defocusing versus distance at times short compared to the convection time for the case of propagation in the atmosphere.

In summary, our experiments have shown the strong similarity between thermal defocusing in liquids and gases. Consequently, much of the theory that has been developed for the liquids case can be applied to the gas case also.